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Jet Production in Muon-Proton and Muon-Nuclei Scattering at Fermilab E665

Carlos W. Salgado
for the E665 Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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by
Carlos W. Salgado
Fermi National Accelerator Laboratory
P.O.Box 500
Batavia, IL 60510, USA
(for the E665 Collaboration)

ABSTRACT

Measurements of multi-jet production rates from Muon-Proton and Muon-Nuclei scattering at Fermilab-E665 are presented. Jet rates are defined by the JADE clustering algorithm. Rates in Muon-Proton deep-inelastic scattering are compared to perturbative Quantum Chromodynamics (PQCD) and Monte Carlo model predictions. We observe hadronic (2+1)-jet rates wich are a factor of two higher than PQCD predictions at the partonic level. Preliminary results from jet production on heavy targets, in the shadowing region, show a suppression of the jet rates as compared to deuterium. The two-forward jet sample present higher suppresion as compared to the one-forward jet sample.

1. Introduction

Jet production from muon scattering in a wide range of energies and with several targets is explored at the Tevatron experiment 665. Relatively high values of Q^2 (four-momentum transfered, up to 25 $(GeV/c)^2$) are obtained in light targets (H and D) to explore the perturbative QCD regime.[1] These data can be used to study the structure (parton densities) and forces (strong coupling constant, α_s) inside the hadrons. In addition, very low values of x-Bjorken (x_{Bj}, down to 10^{-5}) are obtained, with the limitation of having low Q^2 values, to measure hadronic jet production from nuclear targets (C, Ca and Pb) in the shadowing region.[2,3] Shadowing is the term used to describe the observed phenomenon where the total cross section of a nuclear process is less than A (atomic number) times the respective single-nucleon process. Data on jet production in this regime can be used to study parton propagation and hadronization in nuclear matter.

The E665 collaboration[4] used a open geometry detector. Data were taken during the 1987-88 and 1990-91 Tevatron run periods on H, D, C, Ca, Xe and Pb targets using a muon beam of 490 GeV average energy. The experiment was mainly made up of several layers of proportional and drift chambers inside of and surrounding two large aperture superconducting magnets.

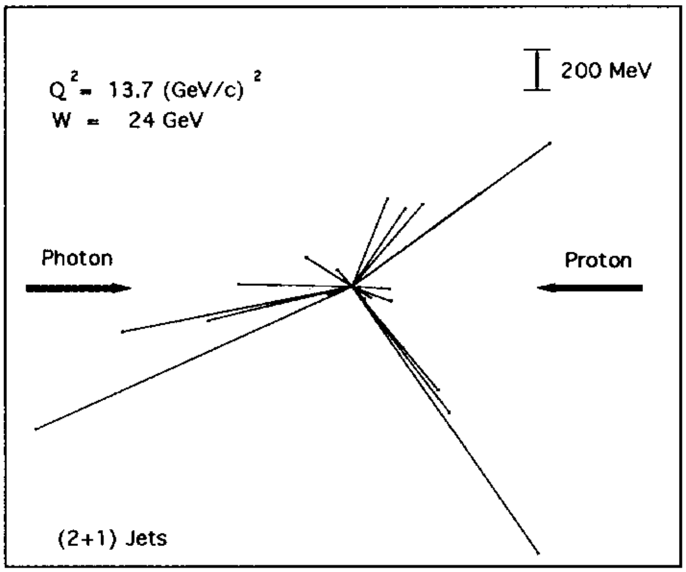

Figure 1: A (2+1)-jet event from the E665 data.

An electromagnetic calorimeter was used to detect electrons and photons. A streamer chamber surrounded the target during the 1987-88 run, and was substituted by vertex drift chambers for the 1990-91 run.

The following standard notation is used in this paper: Q^2 is the negative square of the virtual-photon four-momentum; W is the total hadronic center-of-mass energy and ν is the energy of the virtual-photon in the lab frame. E_{Beam} is the energy of the beam and M the mass of the nucleon.

2. Multi-jet Production on Protons

Data on Muon-Proton deep-inelastic scattering (DIS) are studied to test perturbative QCD. We study events with three jets in the final state, including the proton-remnant jet and two jets from the hard QCD interaction - the (2+1)-jet topology. Those events are produced, at leading-order, by gluon bremsstrahlung from the initial and final partonic states and by photon-gluon fusion. Figure 1 shows an observed (2+1)-jet event. The event has been boosted into the virtual photon-proton center-of-mass system and projected onto the hadronic plane (the plane containing the virtual photon and in which the sum of the squared transverse momenta of the hadrons is maximized). Electronic and streamer chamber information is included.

Charged particles reconstructed in the forward spectrometer and neutral particles reconstructed in the electromagnetic calorimeter are used in the analysis. The event sample is defined using the following kinematical cuts: $4.0 \leq Q^2 \leq 25.0 (GeV/c)^2$, $W \geq 20 GeV$, $\nu \geq 40 GeV$, $x_{Bj} = Q^2/2M\nu > 0.003$ and $0.05 \leq y_{Bj} = \nu/E_{Beam} \leq 0.95$. A calorimeter cut was used to remove coherent photon bremsstrahlung from the sample. Only particles going forward in the center-of-mass system are used in this analysis. All charged particles are considered to be pions and all neutrals particles to be photons.

To define the number of jets in an event the JADE algorithm[5] is used. The (2+1)-jet rates, $R_{(2+1)}$, are defined as the ratios between the number of (2+1)-jet events and the total number of events. The data distributions have been corrected bin by bin using a Monte Carlo simulation of the detector. We estimated the total systematic error coming from our ability to model the detector and from event and particle selection criteria to be less than $\Delta R_{(2+1)} = 0.03$.

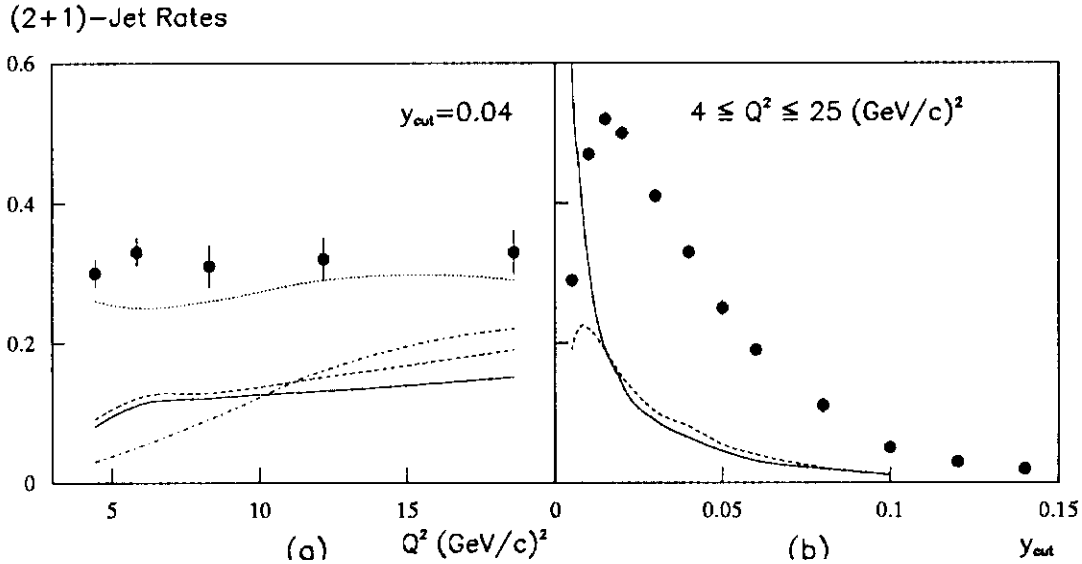

Figure 2: a) (2+1)-jet rates, at the hadron level, versus Q^2, for $y_{cut} = 0.04$. Also shown are the predictions, at the parton level, from various Lepto 6.1 Monte Carlo options: Matrix Elements (ME) (solid), Parton Shower (PS) with default maximum virtuality (dotted-dashed), ME+PS (dashed) and PS with W^2 as maximum virtuality (dotted). b) (2+1)-jet rates, at the hadron level, versus y_{cut}. Also shown are the PQCD predictions at the LO (solid) and NLO (dashed).[7]

Figure 2.a shows the (2+1)-jet rates from the E665 data at the hadron level versus Q^2 for a value of the JADE-jet resolution parameter, $y_{cut} = 0.04$. Only statistical errors are shown. Also shown are the predictions of the (2+1)-jet rates at

the parton level from various Lepto 6.1 Monte Carlo[6] options. Figure 3.b shows the same (2+1)-jet rates from the E665 data at the hadron level versus y_{cut}, for all Q^2. Also shown are the predictions from PQCD at the leading and next-to-leading order (where only transverse polarization of the photon is considered).[7] We observe that the hadronic JADE-jet rates are a factor of two higher than PQCD predictions at the partonic level. We have studied possible causes for this discrepancy. We considered effects of hadronization, clustering, uncertainties on the parton distributions, Λ_{QCD} and scales. We find that the discrepancy is mostly due to the sensitivity of the JADE clustering algorithm to the softer particles in the event. We are currently investigating various modifications of the JADE algorithm, various kinematical cuts on the jet and/or hadron phase spaces and exploring the use of different kind of algorithms to be able to establish a better jet-parton duality for jet rates.

3. Multi-jet Production on Heavy Targets

During the 1990-91 Tevatron run, we observed muon scattering in several heavy targets. We have extended the previous jet analysis to this heavy target data.[8] The JADE algorithm is utilized to defined forward di-jet production rates from C, Ca and Pb targets and these rates are compared to those from D in the kinematical region where shadowing has been observed in the total cross section.[9]

In order to get sufficiently small values of x_{Bj} (shadowing region) the Q^2 cut has been greatly relaxed compared to the one used in the Muon-Proton analysis. The following kinematical cuts are applied to the data: $Q^2 \geq 0.1 GeV^2$, $\nu \geq 40 GeV$, $x_{Bj} \geq 0.001$ and $0.05 \leq y_{Bj} \leq 0.75$. The electromagnetic calorimeter is used to remove the coherent and quasi-elastic $\mu\gamma$ backgrounds. Preliminary results from one third of the data are presented here.
Figure 3 shows the (uncorrected) per nucleon cross section ($\sigma_A = \sigma/A$) ratios (for C/D, Ca/D and Pb/D) versus x_{Bj}, for events with 1+1 (one-forward) and 2+1 (two-forward) jets separately. All ratios show the clear signal of shadowing ($\sigma_A/\sigma_D < 1$) in the region $x_{Bj} < 10^{-2}$. The two-forward jet sample present a higher suppresion as compared to the one-forward jet sample. The data shown is uncorrected for acceptance, resolution and tracking inefficiencies. However, in order to reduce systematics, E665 rotated its targets every few minutes and therefore these corrections should cancel in the ratios. We have studied the effects from the differences in radiation and interaction lenghts among the targets. We conclude that such effects are small. More detailed studies with the full data sample are underway.

4. Conclusions

Multi-jet production rates have been measured in Muon-Proton and Muon-Nuclei scattering at Fermilab-E665. The JADE clustering algorithm is used to define jets. From the Muon-Proton sample, at relative high Q^2, we obtain hadronic jet rates

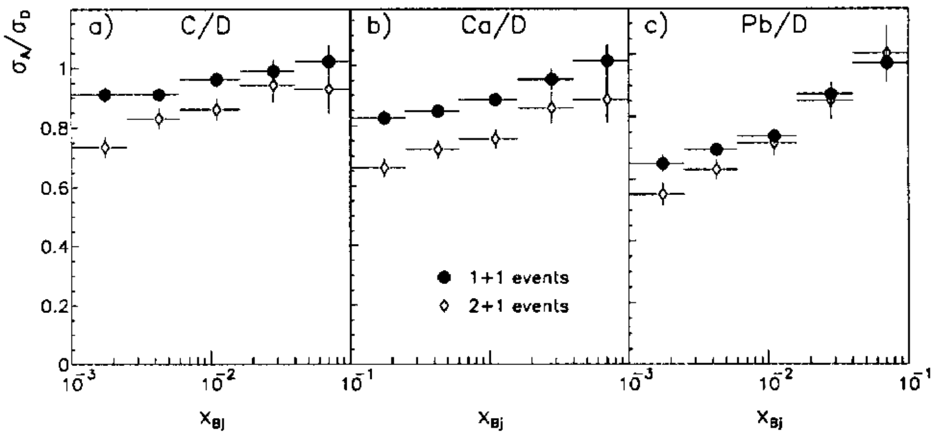

Figure 3: Per nucleon cross section ratios for events with 1+1 jets and 2+1 jets at $y_{cut} = 0.04$ versus x_{Bj} for C/D, Ca/D and Pb/D.

with factors of two higher rates than predicted by PQCD at the partonic level. We have studied several possibilities to explain this discrepancy. Our preliminary conclusion is that the discrepancy is mainly caused by defficiencies in the JADE clustering to reproduce phase space cuts introduced in the PQCD calculations (to solve soft and collinear singularities) when a significant high number of soft hadrons are present.

First preliminary measurements of multi-jet events on nuclear targets in the shadowing region indicate a suppression of multi-jet events in heavy targets as compared to D. This suppresion is higher in the (2+1)-jet sample than the (1+1)-jet sample. These data may help us to investigate models of shadowing and the gluon distributions within the nuclei.

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